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Quad-Emissive Display for Multi-Spectral Sensor Analysis

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1.0 SUMMARY

The Quad-Emissive Display (QED) is a device that is designed to provide suitable emissive energy in four spectral bands to permit the simultaneous evaluation of sensors with different spectral sensitivities. A changeable target pattern, such as a Landolt C, a tumbling “E”, a triangle or a bar pattern, is fabricated as a stencil (cutout) that is viewed against a second, black surface located several centimeters behind the stencil and thermally isolated from the stencil target. The sensor spectral bands of interest are visible (0.4 to 0.7 microns), near infrared (0.7 to 1.0 microns), short wave infrared (1.0 to 3.0 microns) and the long wave infrared (8.0 to 14.0 microns). This paper presents the details of the structure of the QED and preliminary results on the types of sensor/display resolution measurements and psychophysical studies that can be accomplished using the QED.

2.0 INTRODUCTION

The resolution of an imaging system is often used as a metric indicating the imaging quality that it is capable of and therefore the level of visual performance that one could expect when using the system^[1]. In recent years, there has been widespread interest in fusing images from different sensors representing different electromagnetic spectral bands in an effort to enhance the visual information content of the image. The underlying assumption is that different spectral bands may provide different visual information content and if one can fuse the “best” (most informative) part of each sensor band image into a single image, one may improve visual performance. The assumption is that visual performance with the fused image should be superior compared to visual performance obtained with any of the component images used to create the fused image.

The question arises as to whether or not a measurement of the “resolution” of the fused image would correlate with the level of visual performance obtained using the fused image. In order to address this question, it is necessary to measure the resolution of each of the component imaging systems (e.g., visible, near-infrared [NIR], short-wave infrared [SWIR], long-wave infrared [LWIR]) and to measure the effective resolution of the fused image created from the component imaging bands. In order to reduce variance as much as possible, it is desirable to have a resolution target that can provide a “high contrast” image in all spectral bands simultaneously. This is the basic motivation behind the development of the Quad-Emissive Display (QED; USA patent pending). The following section provides a description of the main features of the QED and its capabilities.

3.0 DESCRIPTION OF THE QED

As the name implies, the QED provides a resolution test pattern that can be sensed in four (quad) different spectral bands simultaneously. The four spectral bands are: visible (0.4 to 0.7 microns), near infrared (0.7 to 1.0 microns), short-wave infrared (1.0 to 3.0 microns) and long-wave infrared (8.0 to 14.0 microns). The resolution test pattern is selectable and can be any test pattern that can be fabricated as a stencil (cutout). This includes a pattern such as a Landolt C, a tumbling “E”, a square-wave grating, tri-bars^[2], Blackwell disks^[3], or triangles^[4] (for triangle

orientation detection or TOD type tests). The stencil approach is not suitable for test patterns that require more than two signal levels such as sine-wave gratings.

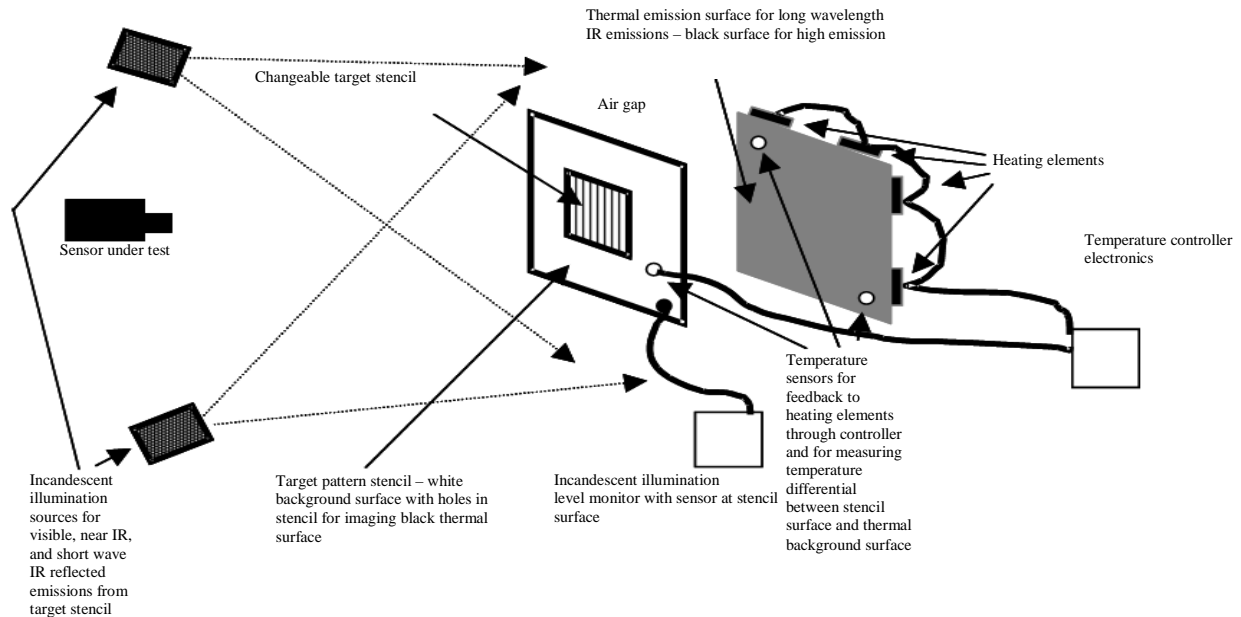


Figure 1. Component schematic of the QED

Figure 1 shows a schematic of the arrangement of components that make up the QED. As shown in Figure 1, the QED has two primary surfaces that create the final resolution pattern image. The first surface of the QED is an opaque, white plastic surround measuring approximately 61cm by 61cm that has a square cutout in the center measuring 30.5cm by 30.5cm. The resolution target stencil is positioned in the square cutout and is also machined from opaque, white plastic.

The second surface of the QED, located approximately 37.5cm behind the first surface, is composed of two aluminum plates with a total thickness of about 9.5mm. The front plate is painted black and the rear plate has the heating elements mounted to its back. The rear surface is heated to provide a thermal differential between the front surface of the QED (the stencil surface), which is at ambient room temperature, and the rear surface. Two incandescent light sources provide illumination for the front surface and the target stencil. As shown in Figures 2 and 3 below, the incandescent illumination provides the electromagnetic energy for the visible, NIR, and SWIR bands and the thermal differential provides the energy for the thermal or LWIR band sensor.

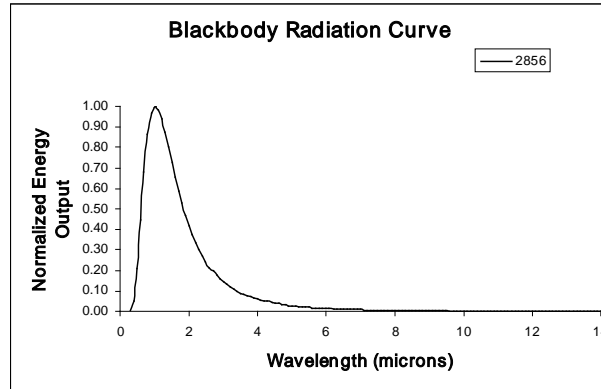


Figure 2. Incandescent spectrum 2856K source

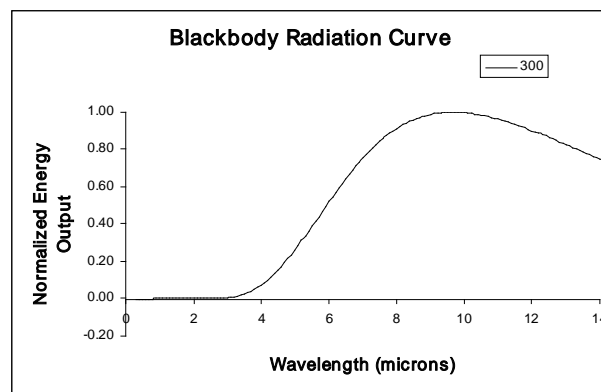


Figure 3. Blackbody spectrum for 300K

Temperature sensors on the two surfaces provide feedback to the temperature controller to maintain a relatively constant temperature differential. The maximum temperature differential that the current prototype is capable of producing is about 11K (11 degrees C). Three temperatures are displayed on the controller: (1) the front surface of the target or ambient temperature, (2) the rear surface of the target or background temperature, and (3) the differential temperature setting.

Figure 4 shows a picture of the device from the side such that the two surfaces that compose the resolution image are easily visible. Figure 5 shows the view from the sensor location. Sensor focus is set for the front surface since that is the only surface that provides any edge detail.

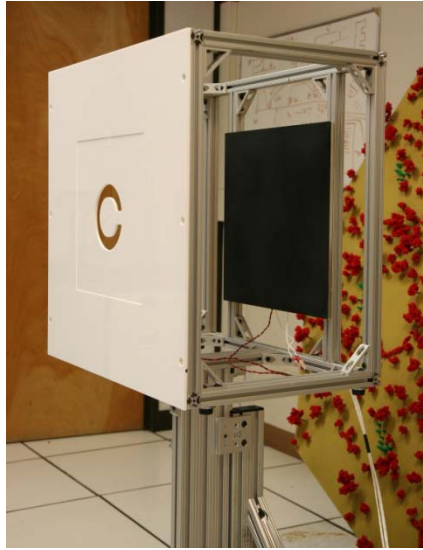


Figure 4. Side view of QED

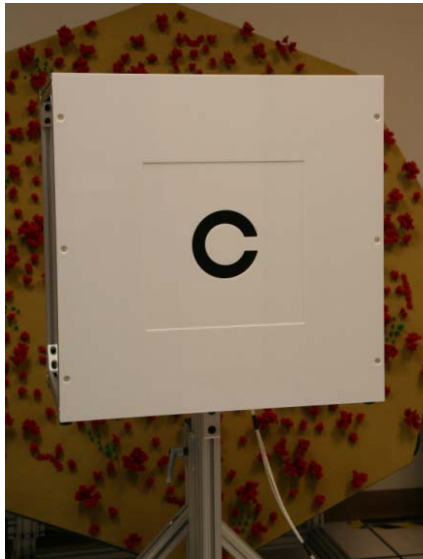


Figure 5. Front view of the QED

The QED is located in a long, light-controlled room to allow sensors to be tested at various distances ranging from 2.7 meters to 46.9 meters ^[5]. Figure 6 shows the movable cart (lower right-hand corner) on which sensors (or observers) can be positioned for evaluating different sensors (or different resolution target patterns).



Figure 6. Sensor evaluation facility

Figure 7 shows an array of four sensors that is mounted to the front of the movable cart shown in Figure 6. The four sensors include visible, NIR, SWIR, and thermal cameras that are generally pointed in the same direction toward the target pattern (or terrain board depending on requirements). The quad spectral band nature of the QED allows for the simultaneous assessment of all four cameras imaging the four spectral bands.



Figure 7. Four sensors mounted on the movable cart

In addition to the longitudinal movement between the sensor and the QED target pattern provided by the computer-controlled, movable cart, the QED also allows precise lateral movement (left-right) using a manually controlled screw mechanism. Up to 10cm of lateral movement is possible to investigate sensor detector array sampling effects with respect to the horizontal features of the target pattern. A future modification to the QED is planned to allow a similar range of precise vertical movement to extend this capability.

4.0 THE QED IN USE – PRELIMINARY RESULTS

There are at least two ways that the QED can be used to assess the resolution of a sensor: 1) produce a series of images of the target pattern at different distances using the moveable cart and present the images of the target pattern to trained observers to obtain a frequency-of-seeing curve^[6] or 2) have the observer seated in the cart while it is dynamically moved toward the target pattern until the observer can accurately determine the critical aspect of the resolution target (usually orientation of the target or visibility of the structure of the grating if a grating is used)^[7]. There are advantages and disadvantages to each method.

The first method takes time to collect sufficient images at several distances (e.g., five to seven distances) so that they can be presented to the observers at a later time to produce a frequency-of-seeing curve. This is a much easier and overall, faster procedure for the observers in that they spend minimal time actually observing the target patterns on a display. Care must be taken to insure the display image quality and the observer viewing conditions are not the limiting factors in judging sensor performance. Since observers and displays are always a part of the sensor assessment procedure, they will always impact the results to some degree. The objective is to minimize that impact when assessing the sensors. One disadvantage of this approach is that it does not include dynamic effects so that any sampling artifacts that are captured in the original images are not “averaged out” by the dynamic sampling that occurs with the moving cart approach (sampling issues are briefly discussed in a later section).

The second method has the advantage of relative motion and dynamic sampling but requires considerably more time to complete. In addition, one does not obtain a frequency-of-seeing curve but a simple end point resolution measurement with whatever error rate occurs. Error rates can be affected by instructions to the observers regarding “guessing” with respect to the orientation of the target pattern.

To date, neither method has been fully implemented using the QED but the first method is currently in the process of being evaluated. Preliminary results look promising but it is still a time-consuming approach.

5.0 TARGET PATTERNS AND SAMPLING ISSUES

One issue that has become exceedingly apparent in the initial evaluation of the QED and sensor resolution assessment procedures is the selection of the specific resolution target pattern to be used with the QED. A Landolt C, a grating pattern (six cycles), and several triangle targets have been fabricated in stencil form for the QED. A four-bar grating pattern is referenced in STANAG 4349 for determining the minimum resolvable temperature difference (MRTD) of thermal imagers^[8]. Landolt C patterns and tri-bar targets have been used to assess image intensifier tubes in night vision goggles (NVGs)^[9]. These target patterns may be reasonably well suited to make resolution measurements of continuous (or quasi-continuous) imaging systems but produce variable results with sensors that essentially “sample” the target pattern with a two-dimensional rectilinear array of sensing elements.

As an example, Figures 8 and 9 show images of a Landolt C that were taken using a visible spectral band camera with a two-dimensional CCD array. Both images were taken at the same distance and with the gap in the “C” at the top. The only difference is the lateral position of the Landolt C with respect to the sensing elements of the camera. In Figure 8, the gap falls on more than one element of the sensor array resulting in a low contrast gap that is two pixels wide; making it difficult to judge that the orientation of the “C” is with the gap to the top.

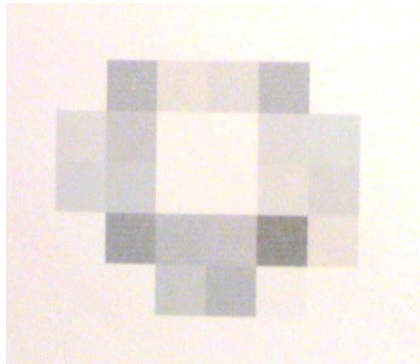


Figure 8. Landolt C with gap at the top falling on two elements of the camera sensor array

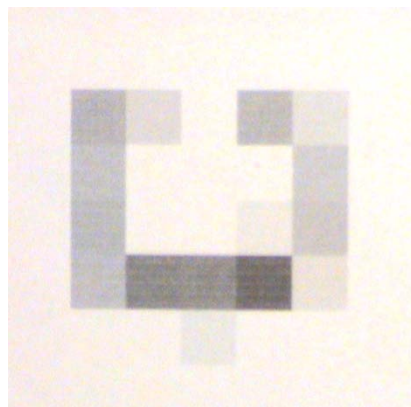


Figure 9. Landolt C with gap at the top falling on essentially one element of the camera sensor array

Figure 9 shows the same Landolt C image taken at the same distance but with the QED horizontal positioning capability used to position the gap so that it falls on essentially a single sensor element. This implies that the resolution results obtained in assessing a sensor may depend on the relative position of the Landolt C with respect to the sensor array; not a desirable effect.

Similar sampling artifacts occur with grating or bar type resolution patterns^[10]. The image obtained depends heavily on the phase (lateral position) of the target pattern with respect to the sampling elements. At the extreme, if a sensor is located a distance from a bar or grating pattern such that the sensor element spacing is exactly equal to the bar width, then one can theoretically obtain an image of the bar pattern that is near 100 percent modulation (contrast) or zero percent modulation depending on the phase. If the detector elements are exactly lined up with the bar

pattern, then one obtains the high contrast result. If the detector elements are exactly 90 degrees out of phase (sensor elements are centered on the edge between the light and dark bars), then one obtains a uniform signal equal to the average of the light and dark bars. The distance at which this occurs corresponds to the Nyquist limit for the sensor/grating target-pattern combination.

At distances other than the Nyquist distance for this bar-type target pattern, one can obtain patterns that vary in signal output levels but do not provide a good representation of the original target pattern. Figure 10 is a baseline image of the six-cycle grating target (50mm per cycle) taken at close range with a high-resolution camera. Figures 11 through 13 show the six-cycle QED grating pattern as it appears at different distances using a visible band camera with a pixel resolution of 0.93 milliradians. Note that one doesn't get a pattern that provides a reasonable representation of the original target until one gets within a distance of about one-quarter of the Nyquist distance meaning there are approximately eight samples per cycle across the target.

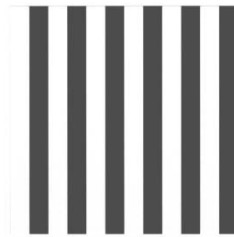


Figure 10. Six-bar (cycle) grating target baseline

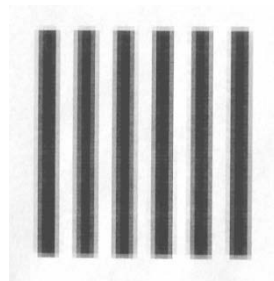


Figure 11. Grating target image from visible camera at one-quarter of Nyquist distance

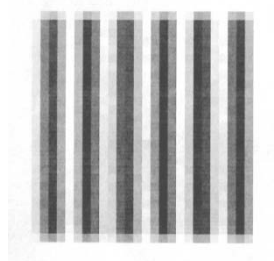


Figure 12. Grating target image from visible camera at one-half of Nyquist distance

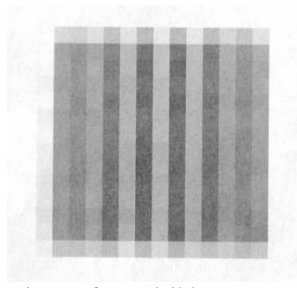


Figure 13. Grating target image from visible camera at Nyquist limit distance

As a means of reducing sampling effects in the evaluation of sensors, it has been proposed to use equilateral triangle orientation detection (TOD) as a target and method ^[4]. Several papers have been published on this target pattern and procedure ^[11,12,13,14] indicating that it is a promising alternative to other traditional resolution patterns and does not suffer from sampling effects to the degree that other target patterns do.

The triangles are oriented with one corner pointed up, down, left, or right. A frequency-of-seeing curve is produced by using different sized triangles to capture the percent correct as a function of the target size. Once the frequency-of-seeing curve is determined for a particular sensor, an appropriate correct probability level can be selected as defining the resolution (such as the triangle size for a 75% correct response rate).

The triangle target “size” is defined as the square-root of the area of the triangle, which is equal to about 0.658 times the length of the side of the triangle. Since the triangle does not have any recognizable critical dimension such as the bar width for gratings or the gap size for the Landolt C, it is a little more difficult to equate the triangle size that corresponds with a specific size Landolt C or grating. However, a preliminary observation comparing Landolt C gap size angular subtense required for detection of the gap with the angular subtense of a triangle target indicate the corresponding critical triangle dimension is about one-quarter of the length of one of the sides. This is very close to the average angular subtense calculated from data presented in ^[14]. This would imply that if one wanted to generate a triangle size that was approximately equivalent to a Landolt C set for 20/20 Snellen vision (angular subtense of the gap being 1 arc minute) then one would need a triangle with a side dimension of about 4 arc minutes. This helps to conceptualize the equivalency between sizes of triangles and sizes of more traditional resolution target patterns. Note that this was done for naked eye viewing with no intervening sensor/display system.

Figure 14 is a high-resolution image of a QED triangle target that is 75mm on a side. Figures 15 through 17 show images of a triangle target taken at some of the same distances as the grating target shown previously (using the same visible-band camera). All images were taken with the triangle pointed “up”.

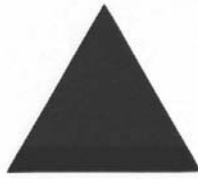


Figure 14. High-resolution image of the QED triangle target stencil (75mm on a side)

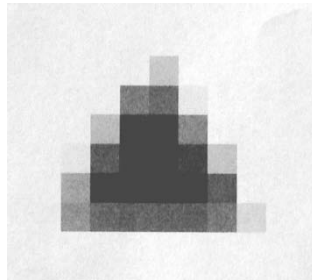


Figure 15. Triangle target image from visible camera at same distance as Figure 12

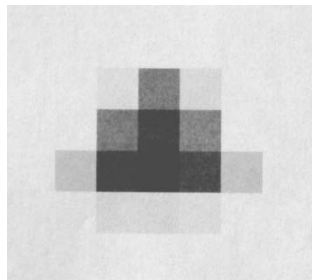


Figure 16. Triangle target image from visible camera at 1.5 times Figure 15 distance

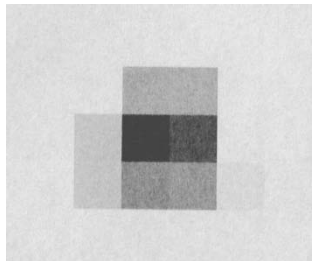


Figure 17. Triangle target image from visible camera at 2 times Figure 15 distance

One observation with respect to the TOD procedure is that with the current convention of orienting the triangles up, down, left, or right, there is always one edge (and only one edge) that is parallel with the sensor array elements (assuming the sensor has a rectilinear array and is oriented in traditional fashion). The ability to detect the orientation of the triangle may be affected by whether this one edge falls exactly at the demarcation between pixel rows thus producing a long, high contrast edge or if the edge falls exactly on the center of a pixel row (or column) producing a two-pixel wide edge resulting in a softer contrast transition between triangle and background (see Figure 16). One way to eliminate this effect is to change the orientation set from the up, down, left and right directions to the upper-left, upper-right, lower-

left and lower-right orientation set. In other words, use a set that is a 45-degree rotation from the current set. This would insure that no edge of the triangle would ever line up with a row or column of sensor elements thereby preventing the possibility of a high contrast edge in the image being used as an orientation cue.

6.0 CONCLUSIONS AND FUTURE EFFORTS

Preliminary assessment of the QED indicates that it functions as designed and should be useful in assessing different spectral-band sensors and the resulting fused images. The next project using the QED is to determine which target stencil and procedure produces the most reliable and useful sensor assessment results. It is expected that the Landolt C, grating pattern and triangles (TOD) will be investigated using the QED. In addition, an investigation will be made into the potential usefulness of using a modified TOD procedure wherein the target set is presented (diagonally) in upper-left, upper-right, lower-left, and lower-right orientations to eliminate the alignment of triangle edges with pixel row/column directions.

Once a resolution evaluation target type is established, studies will be conducted to determine if the measured resolution of the sensor images (using the QED) can successfully predict visual performance capability of the separate spectral band images and the fused images produced from the different spectral band images.

Since this paper was written, a third evaluation approach has been developed that appears promising. This approach uses a computer algorithm to detect the orientation of the Landolt C generated from the sensors imaging the QED. The objective is for the computer software to emulate the Landolt C orientation results that would be expected of a human observer viewing the imagery. Preliminary results are encouraging and this approach is being aggressively pursued as potentially the best method of implementing the QED sensor resolution assessment.

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ABBREVIATIONS AND ACRONYMS

CCD – Charged-coupled Device

LWIR – Long-Wave Infrared

MRTD – Minimum Resolvable Temperature Difference

MWIR – Medium-Wave Infrared

NIR – Near Infrared

NVGs – Night Vision Goggles

QED – Quad-emissive Display

SPIE – International Society for Optics and Photonics

STANAG – North Atlantic Treaty Organization Standardization Agreement

SWIR – Short-wave Infrared

TOD – Triangle Orientation Detection